

## Extraction of the $D_{13}(1520)$ photon-decay couplings from pion- and eta-photoproduction data

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### Abstract

We compare results for the  $D_{13}(1520)$  photon-decay amplitudes determined in analyses of eta- and pion-photoproduction data. The ratio of helicity amplitudes ( $A_{3/2}/A_{1/2}$ ), determined from eta-photoproduction data, is quite different from that determined in previous analyses of pion-photoproduction data. We consider how strongly the existing pion-photoproduction data constrain both this ratio and the individual photon-decay amplitudes.

Recent precise measurements of eta-photoproduction observables have spawned a number of analyses, focused mainly on the properties of the  $S_{11}(1535)$  resonance[1]. These studies have found values for the photo-decay amplitude,  $A_{1/2}^p$ , which are significantly larger than those found in previous analyses of pion-photoproduction data[2]. As the  $S_{11}(1535)$  resonance is masked by a strong  $\eta N$  threshold cusp in pion photoproduction, eta-photoproduction holds the promise of a less model-dependent analysis. Attempts to fit pion- and eta-production data in coupled-channel approaches[3, 4] have generally found values between those extracted from single-channel fits.

Two studies[5, 6] have gone beyond the  $S_{11}(1535)$  and have considered the sensitivity of eta-photoproduction data to the nearby  $D_{13}(1520)$  resonance. In both of these analyses, values for the *ratio* of photo-decay amplitudes,  $A_{3/2}/A_{1/2}$ , were found to be consistently far smaller than those inferred from pion-photoproduction analyses[7]. This discrepancy is certainly unexpected[8], as the  $D_{13}$  state appears to have a clean Breit-Wigner-like signal in the associated multipoles  $E_{2-}^{1/2}$  and  $M_{2-}^{1/2}$  extracted from pion-photoproduction data. This ratio, as determined from eta-photoproduction data, has the value  $-2.5 \pm 0.2 \pm 0.4$ [5] or  $-2.1 \pm 0.2$ [6], as compared to the PDG estimate[9] of  $-6.9 \pm 2.1$ . Eta-photoproduction has the advantage of

isospin selectivity but, in the case of the  $D_{13}(1520)$ , one must deal with a very small coupling to the  $\eta N$  channel.

As this difference amounts to a shift by several standard deviations in a supposedly well-determined quantity, we have considered whether the eta-photoproduction result can be accommodated, even qualitatively, by the existing pion-photoproduction database. Given that we are investigating a very large effect, and the background contribution to the  $E_{2-}^{1/2}$  and  $M_{2-}^{1/2}$  multipoles appears to be small near the resonance energy, this study was carried out assuming resonance dominance in both the eta- and pion-photoproduction multipoles[10]. Clearly this implies our results will only be qualitative. However, as we will see, even qualitative results can be revealing.

We first note that the ratio of modified multipole amplitudes, corresponding to the ratio  $A_{3/2}/A_{1/2}$  is given by

$$\frac{A_{3/2}}{A_{1/2}} = \sqrt{3} \left( \frac{\bar{E}_{2-} + \bar{M}_{2-}}{\bar{E}_{2-} - 3\bar{M}_{2-}} \right) \quad (1)$$

with conversion factors as given in, for example, Ref.[11]. Since we will be dealing with ratios, the conversion factor is not relevant and we will drop the barred notation. Assuming resonance dominance, a ratio of  $-2.5$  for  $A_{3/2}/A_{1/2}$  can be converted to a ratio of about  $1.4$  for  $E_{2-}^{1/2}/M_{2-}^{1/2}$ . This can be compared to the result of a representative analysis of pion-photoproduction data[12], wherein the ratio of multipoles (imaginary parts) is found to be about  $2.1$  at the resonance energy[14].

In order to gauge the sensitivity of pion-photoproduction data to this ratio, we started with a single-energy analysis centered at a lab photon energy of  $760$  MeV, corresponding to a value of  $\sqrt{s}$  near the  $D_{13}(1520)$  resonance position. We then considered the effect of changes in the fitted multipoles. Some qualitative results were immediately noticed. If one  $D_{13}$  multipole was fixed and the other ( $E_{2-}^{1/2}$  or  $M_{2-}^{1/2}$ ) was shifted to achieve a ratio of  $1.4$ , the cross sections for both  $\pi^0 p$  and  $\pi^+ n$  production were missed by large margins. However, if  $E_{2-}^{1/2}$  was reduced and  $M_{2-}^{1/2}$  was increased in magnitude, a qualitative description of the cross sections could be retained. A good fit to the existing polarization data was also preserved. It soon became apparent that a *small* increase in  $M_{2-}^{1/2}$  and a *moderate* decrease in  $E_{2-}^{1/2}$  was preferred in this exercise. From Eq. (1) this implies a small decrease in  $A_{3/2}$  and a larger increase in the magnitude of  $A_{1/2}$ ; results following the trend suggested in Refs.[5, 6].

In Fig. 1 we show the result of increasing  $M_{2-}^{1/2}$  by 15% and fixing the  $E_{2-}^{1/2}/M_{2-}^{1/2}$  ratio at 1.4. For comparison purposes, we also show the result of a shift in  $M_{2-}^{1/2}$  alone, leading to the required ratio. The backward-angle cross sections are particularly sensitive to these changes, as the  $D_{13}$  multipoles enter in the combination  $(E_{2-}^{1/2} - 3M_{2-}^{1/2})$ . The larger  $M_{2-}^{1/2}$  and smaller  $E_{2-}^{1/2}$  both reduce the cross section at back angles. Polarization measurements, in the current data base, are not sufficiently precise to pin down  $E_{2-}^{1/2}$  and  $M_{2-}^{1/2}$ . The relative insensitivity of recoil polarization is illustrated in Fig. 2. A somewhat greater sensitivity is seen in the beam-polarization observable ( $\Sigma$ ). It should be emphasized that this is *not* a fit to the pion-photoproduction data. As mentioned above, a fit would result in very different values for the multipoles. Here we are simply showing how the conclusions of Refs.[5, 6] would effect the existing fit to pion-photoproduction data, near the  $D_{13}$  resonance position.

In summary, properties of the  $D_{13}$  multipoles, as determined from fits to eta-photoproduction data, are not entirely excluded by the existing pion-photoproduction data. It is possible to obtain a qualitative description (but not a  $\chi^2$  fit) of the pion-production data, at the resonance position, consistent with an  $A_{3/2}/A_{1/2}$  ratio near  $-2.5$ . If this ratio were correct, and effects from the background were not a problem, the next step would be to determine which data, in the pion data base, were incompatible with this result. At present this would be difficult, as the data base is rather sparse, with few sets covering a wide angular range. We suggest a similar study should be interesting if performed on the eta-photoproduction data base. In that test one would assume the  $D_{13}$  ratio, as extracted from pion-production data, and consider what changes in the other multipoles would be required for a qualitative fit.

A second implicit assumption in this study should also be mentioned. We have considered the effect of changes in the  $D_{13}$  multipoles *assuming* the remaining multipoles to be correct. Given the above mentioned discrepancy between eta- and pion-photoproduction results for the  $S_{11}(1535)$ , this assumption could be questionable for the S-wave multipoles. As an exercise, we fixed the  $E_{2-}^{1/2}/M_{2-}^{1/2}$  ratio at the resonance point, and fit the full database to 1.2 GeV. In this fit, as might be expected, the  $E_{0+}^{1/2}$  multipole showed the largest shift due to the constraint. More definitive tests will be possible when precise measurements of the cross section and polarization observables cover

this region. Precise measurements at backward angles will be particularly useful.

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the pion- and eta-photoproduction results. See Ref.[5] for a discussion of the various quark model predictions.

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## FIGURE CAPTIONS

Figure 1. Differential cross section for  $\gamma p \rightarrow p\pi^0$  at 762 MeV. Data from Ref.[15]. Solid curve corresponds to the unmodified single-energy solution; dashed curve corresponds to a 15% increase in the imaginary part of  $M_{2-}^{1/2}$  and the proposed  $A_{3/2}/A_{1/2}$  ratio (-2.5); dotted curve corresponds to the proposed ratio assuming the largest multipole ( $E_{2-}^{1/2}$ ) is correct.

Figure 2. Recoil polarization for  $\gamma p \rightarrow p\pi^0$  at 762 MeV. Data, between 760 and 765 MeV, from Ref.[16]. Curves as given in Fig. 1.





